TP 6253E

A GUIDE TO LIGHT BULB ANALYSIS

IN SUPPORT OF AIRCRAFT ACCIDENT INVESTIGATION

Prepared for the
Transportation Development Centre
Transport Canada

By

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TP 6255E

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LIGHT BULB ANALYSIS

IN SUPPORT OF AIRCRAFT ACCIDENT INVESTIGATION

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by

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in co-operation with
The Aviation Safety Engineering Branch
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17. Abstract

This manual is to assist aircraft accident investigators in the analysis of light bulb filaments. It describes and illustrates hot and cold bulbs subjected to controlled impact simulating an aircraft crash, and is based on a cooperative research program conducted by the Transportation Development Centre and the Aviation Safety Engineering branch of the Canadian Aviation Safety Board.

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17. Résumé

Ce guide s'adresse aux personnes chargées des enquêtes sur les accidents d'avions et concerne la technique d'investigation par analyse des filaments d'ampoule. Il décrit, illustrations à l'appui, le mécanisme de rupture des filaments d'ampoule chauds et froids soumis à des impacts contrôlés simulant les conditions d'un écrasement. Il est le fruit d'un programme de recherche mené conjointement par le Centre de développement des transports et la Direction techniques de sécurité aérienne du Bureau canadien de la sécurité aérienne.

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F O R E W O R D

The major factor in the decision to conduct extensive research into aircraft light bulb behaviour under impact was the realization of the potential of light bulb filament investigation as an aid to aircraft accident investigation.

This manual was derived from **TP6254E Light Bulb Filament Impact Dynamics** which describes the research conducted under controlled impact conditions by the Aviation Safety Engineering (ASE) Laboratory, Ottawa, Canada.

There is a substantial body of knowledge on the behaviour of automotive light bulbs on impact, but this is based largely on direct impact of the bulbs themselves whereas the research covered by ASE is based largely on filament behaviour under inertia forces.

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1. PURPOSE

The analysis of annunciator panel, warning and illumination light bulbs can lead to the determination of the state ('on' or 'off') of each bulb immediately prior to impact; this analysis is an important facet of aircraft accident investigation.

This information may be used to infer:

1. aircraft operating parameters prior to impact;
2. a qualitative appreciation of the severity of impact.

A three-stage investigation is envisaged:

1. an on-site first look and removal of bulbs from the aircraft;
2. a microscopic examination by a regional laboratory to determine the nature and scope of filament deformation;
3. a detailed analysis by a specialized laboratory.

2. FACTORS AFFECTING FILAMENT DAMAGE

The various factors to be taken into account in analyzing aircraft light bulbs are listed below; each is discussed in some detail with appropriate illustrations on subsequent pages:

1. type and manufacturer of bulb;
2. orientation of the bulb relative to the flight path at impact;
3. applied voltage during the accident sequence;
4. nature and severity of impact;
5. degree of aging.

3. TYPE OF BULB

Three configurations of aircraft light bulbs in common use are illustrated in Figure 1.

The most common type in current use has a single coil filament and two support posts, and is exemplified by types 327

and 313 bulbs. The type 327, manufactured by General Electric, is used in many annunciator panels and is the type used extensively in the research program.

Differences in design and manufacturing processes as well as in bulb configuration could produce impact damage that differs in certain details, but the fundamental principles may be used with discretion in analysing aircraft bulbs other than the GE327.

The filament material used by the major manufacturers was found on analysis to be 99.98% tungsten. Material properties may differ substantially, however, from bulb to bulb due to microstructural changes, dopants and manufacturing processes.

4. ORIENTATION OF BULB

The vibratory motion of support posts under impact, particularly in resonance, has a profound influence on the behaviour of the filament they are supporting. All tests were conducted so that the most severe motion of the support posts occurred i.e. with the direction of local impact in the plane of the posts and perpendicular to the posts.

When impact occurs under any other orientation, the motion of the posts is reduced for a given impact or, conversely, a greater impact would be required to produce the same magnitude of motion.

SINGLE HELIX FILAMENTS - SUPPORTED
GE-313 (left) and GE-327 (right), showing internal components

A-base,
B-glass envelope,
C-contact posts,
D-support posts,
E-glass bead,
F-filament.

SINGLE HELIX FILAMENT
unsupported

DOUBLE HELIX FILAMENT
supported

FIGURE 1: AIRCRAFT LIGHT BULB CONFIGURATIONS

5. APPLIED VOLTAGE

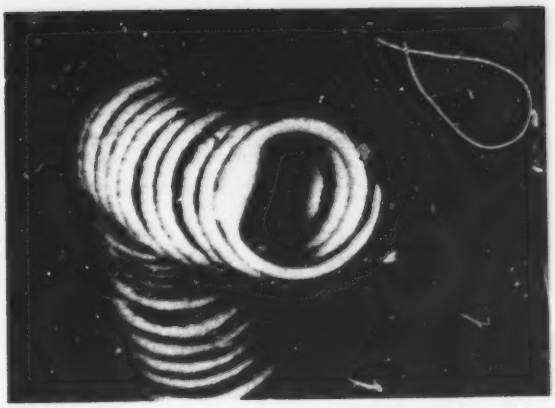
With few exceptions, all of which are suitably annotated, this manual is based on a 28 volt d.c. electrical system which is used on a substantial number of general aviation aircraft. Filament behaviour under inertia forces is significantly different with and without the voltage applied.

With voltage applied, the filament is hot and relatively ductile; without voltage applied, the filament remains cold and relatively brittle. Under inertia forces, therefore, a hot filament may permanently deform whereas a cold filament will generally not. Deforming of the filament while the turns remain tightly coiled is defined as "general deformation"; whereas uncoiling of individual turns is defined as "local deformation (stretch)". Examples of both types of deformation appear throughout this manual.

When a hot filament flails violently during the impact sequence, two or more parts may touch causing a short circuit, which often causes burn-out, as illustrated opposite.

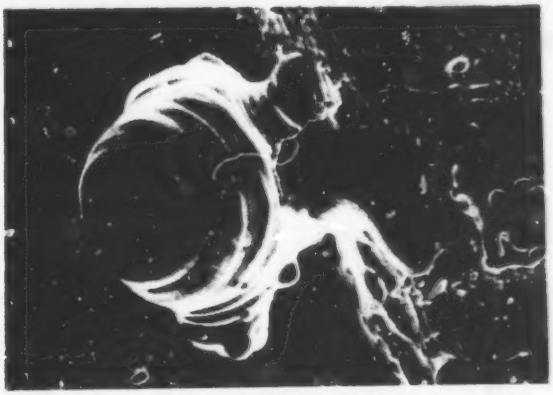
An electrical system fault, not necessarily related to crash impact, may be experienced at any time and may also cause burn-out as illustrated opposite. A burn-out of this nature (high-voltage) exhibits no filament deformation, and typically fractures at one or both contact posts. Burn-out at normal applied voltage, unrelated to crash impact, may occur as a result of local overheating due to severe notching (aging), as illustrated opposite.

Short-circuited filament (x17) showing both general and local deformation.

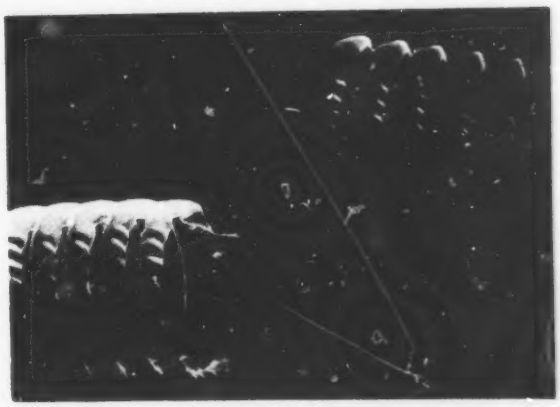


Close-up of same filament (x350) showing characteristic "aneurism".

Result of severe over-voltage (x21) typical of electrical system fault showing fractures at both contact posts.



Close-up of single contact post (x700); note signs of melting.



Typical burn-out (x30) due to severe notching (aging). In this example notching was accelerated by applying 38 volts d.c. Note rounded fracture edges and "aneurism". ⟶

FIGURE 2: EXAMPLES OF BURN-OUT

6. NATURE AND SEVERITY OF IMPACT

In a crash, the kinetic energy of the aircraft is reduced to zero by a combination of deceleration or "g" forces acting over a period of time; the former may reach peaks of several thousand g and the latter may vary from a fraction of a millisecond to several seconds. It is common practice to refer to an average g level acting on the aircraft as a whole during the accident sequence, but local g levels e.g. those on the instrument panel, are typically different from this average. It is these local g forces that affect the condition of the light bulb.

Figure 3 illustrates the relationship between g level and time for a typical impact.

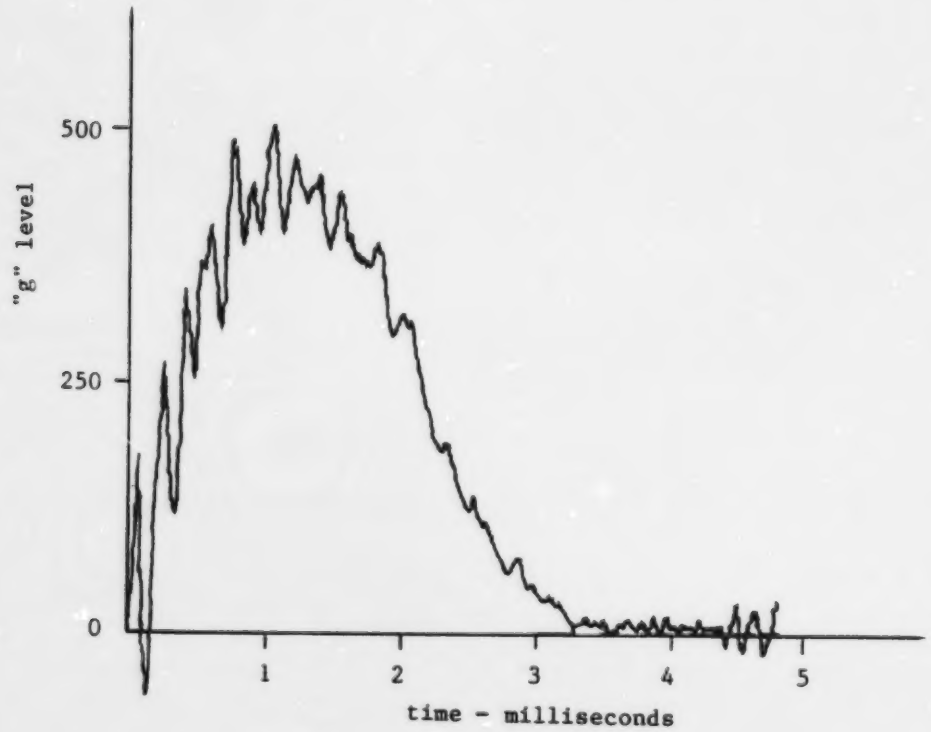


FIGURE 3: IMPACT CHARACTERISTIC CURVE

7. DEGREE OF AGING

When d.c. voltage is applied to a tungsten filament, two significant aging processes occur:

1. Certain crystals within the filament grow at the expense of smaller crystals; this results in an overall reduction in the number of crystals, and a loss of strength.

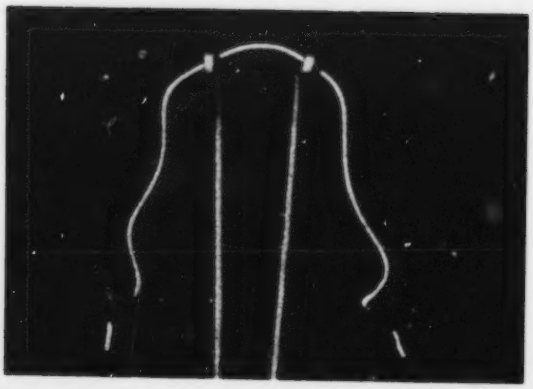
2. Tungsten ions begin to migrate within the filament to preferred crystal planes; this is visible as notching.

Notching occurs over the entire length of the filament except in the immediate vicinity of the contact and support posts where the local temperatures are reduced due to the heat sink effect. The severity of notching increases with time, and local cross-sections gradually become smaller. Thus crystalline changes and notching both act to reduce filament strength with time.

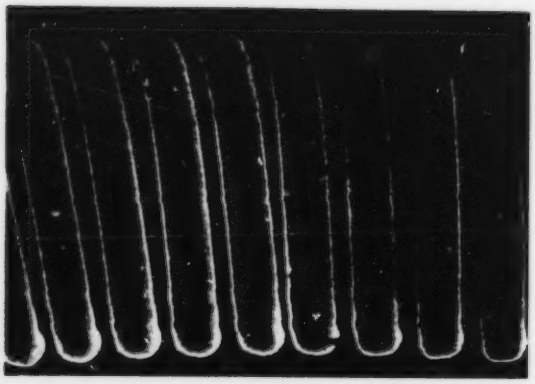
The development of notching is a complex function of applied voltage; the process may be slowed down by reducing voltage or accelerated by increasing voltage.

Applied a.c. voltage does not cause notching, except in the vicinity of heat sinks (support and contact posts) where temperature gradients exist.

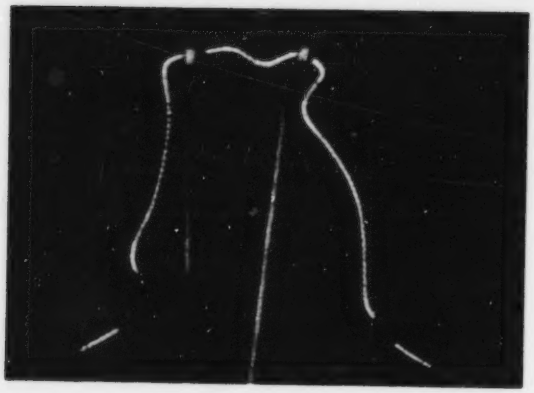
Examples of notching and other aging characteristics are shown in Figure 4. The aging hours refer to exposure to "worst case" cockpit vibration based on flight measurements, with 28 volts d.c. applied.



New filament (x14), showing smooth overall contour.



Same filament (x700), showing smooth surface.

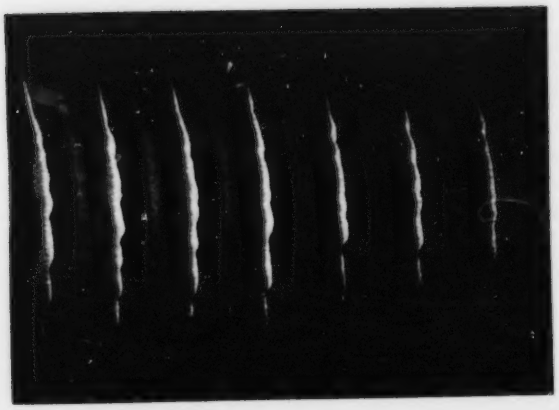


Filament (x14), aged 144 hours, showing distortion in vicinity of support posts.

Same filament (x700), showing relatively light surface notching.

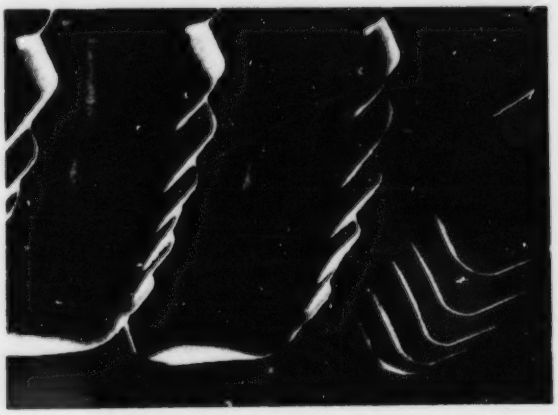
FIGURE 4: FILAMENT NOTCHING

Filament (x14), aged 250 hours, showing more pronounced distortion in the vicinity of support posts.



Same filament (x700), showing growth of notching.

Severely notched filament (x1750), after 500 hours aging.



Severely notched filament (x1750) after 77 hours aging at 38 volts d.c., illustrating the relationship between notching severity and applied voltage.

FIGURE 4: (continued)

8. POST-IMPACT ANALYSIS

This section is devoted to the characteristics that appear following impact; these may be analysed in order to deduce some of the aircraft parameters during and immediately before impact.

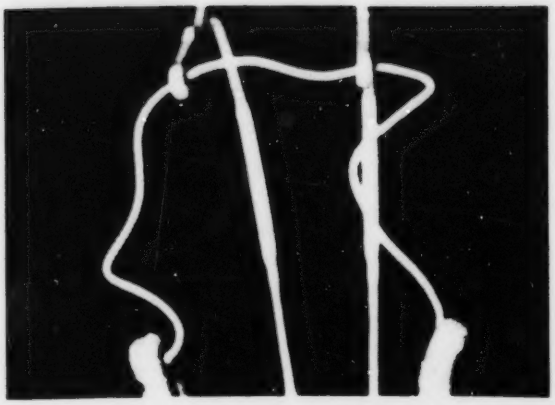
Figure 5 illustrates the interrelationships between applied voltage, aging and impact severity.

The added effect of resonance is illustrated in Figure 6. This elusive characteristic will appear whenever a bulb is exposed to frequencies close to the natural frequencies for the support post-filament system. More importantly, a single impact of short duration (equal or shorter than the natural frequencies) will cause excitation of the support post-filament system.

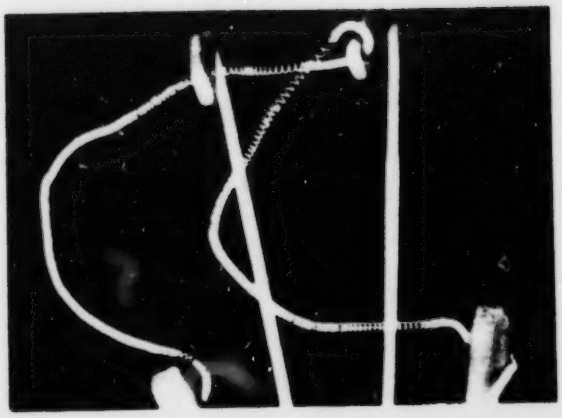
The distinctive appearance of cold fracture faces is illustrated in Figure 7, while the characteristics of filaments that have experienced hot fracture are shown in Figure 8.

Damage boundary curves for hot and cold filaments are shown in Figure 9. These were derived from test data and show clearly the higher threshold of cold bulbs with low age.

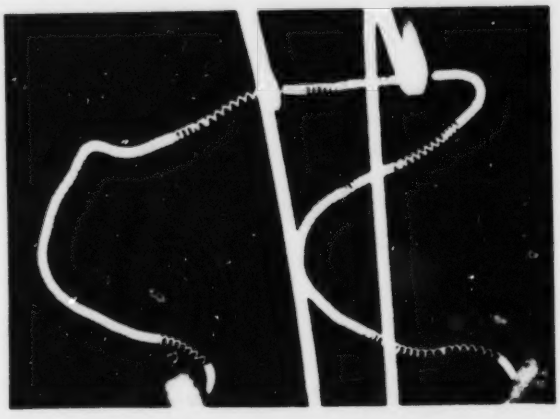
Section 9 presents notes on illumination times to add to the array of facts at the disposal of the investigator conducting the analysis.



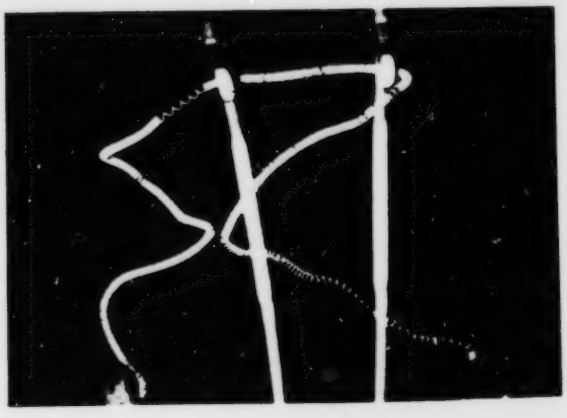
New filament. Note general deformation only.



48 hours age. Note greater general deformation and some local stretch.



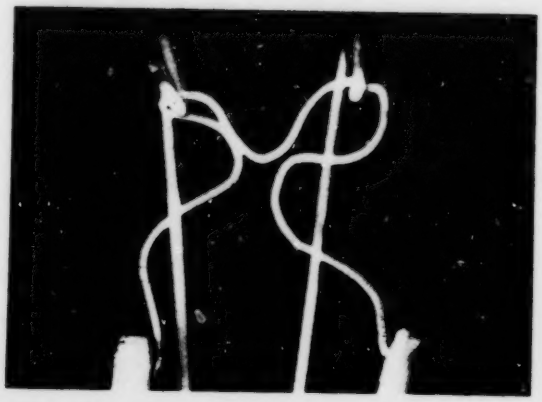
85 hours age. Note increased general deformation and some local stretch.



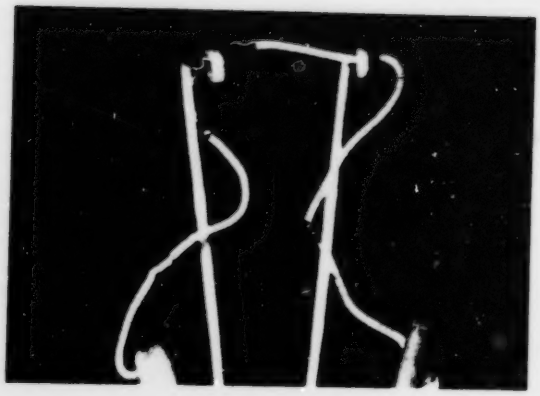
144 hours age. Note severe general deformation and increase in local stretch.

TEST PARAMETERS
1800g
1.0 msec
28 volts d.c.
x21 mag.

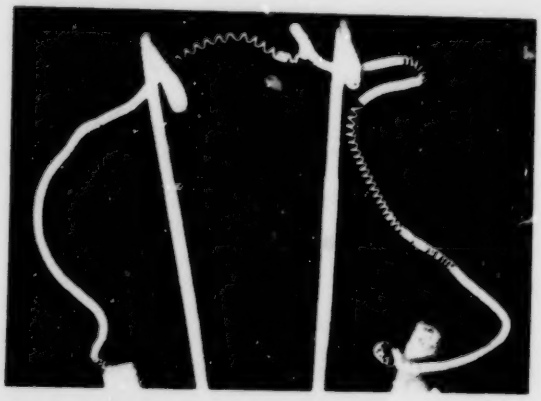
FIGURE 5: FILAMENT AFTER IMPACT



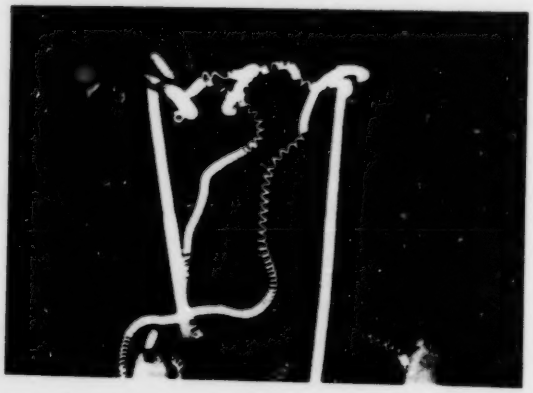
New filament. General deformation greater than on page 11 because of more severe impact; negligible local stretch.



48 hours age. General deformation and local stretch more evident.



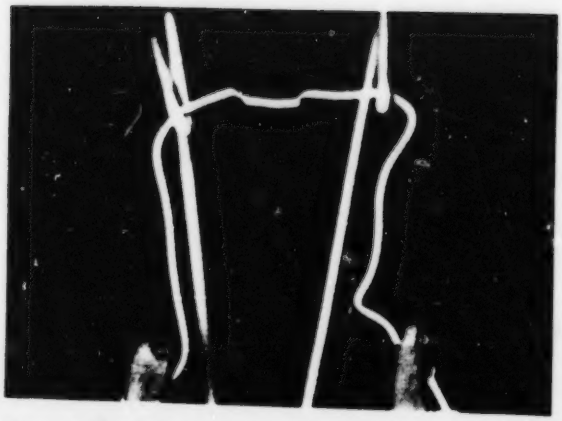
85 hours age. Increase in general deformation and local stretch.



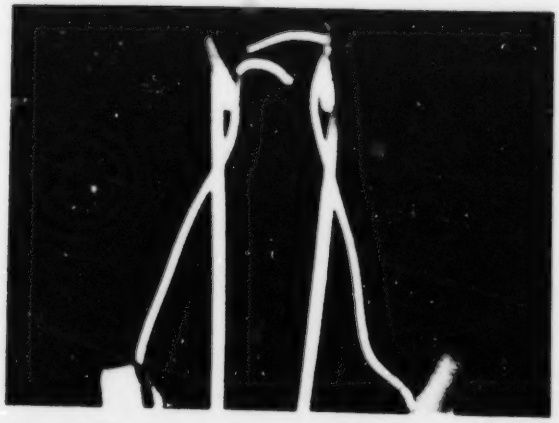
144 hours age. Note extreme general deformation, local stretch and fracture.

TEST PARAMETERS
3500g
1.0 msec
28 volts d.c.
x21 mag.

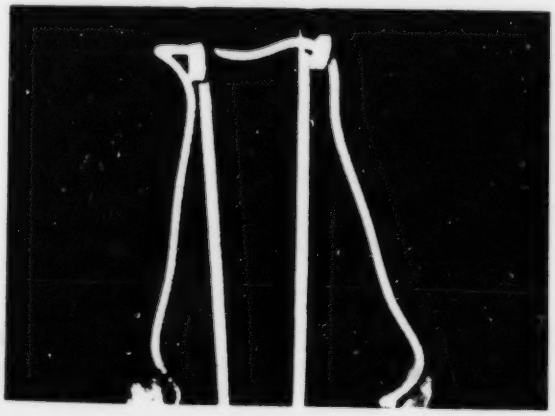
FIGURE 5: (continued)



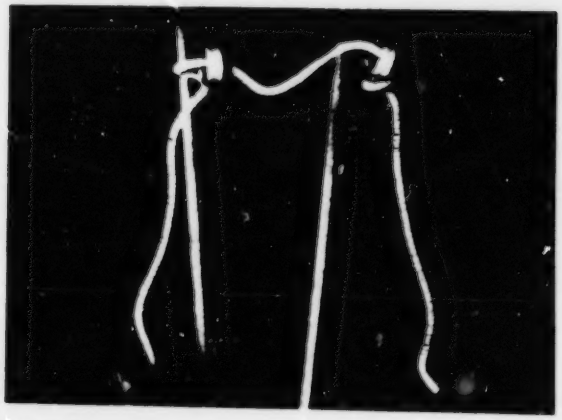
New filament. No sign of general deformation or local stretch due to impact. Slight abnormality in centre of filament attributed to manufacturing process.



48 hours age. No deformation evident, but cold fracture has occurred. Generally bulbs of this age experiencing this impact do not fracture.



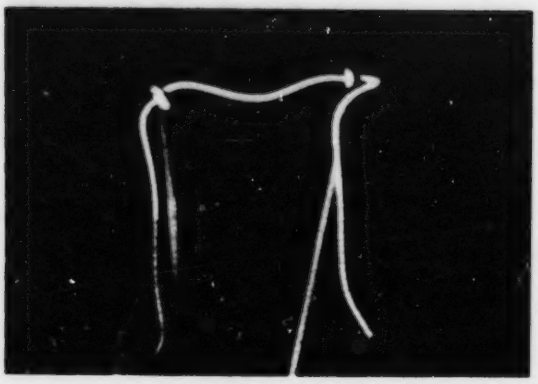
85 hours age. No appreciable change in appearance due to impact.



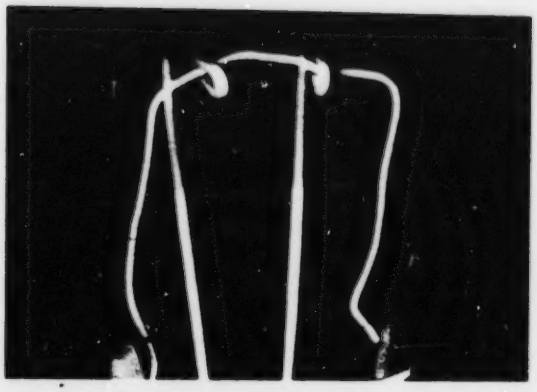
144 hours age. No appreciable change in appearance due to impact. Note normal deformation of filament around support posts consistent with aging.

TEST PARAMETERS
1600g
1.6 msec
0 volts d.c.
x21 mag.

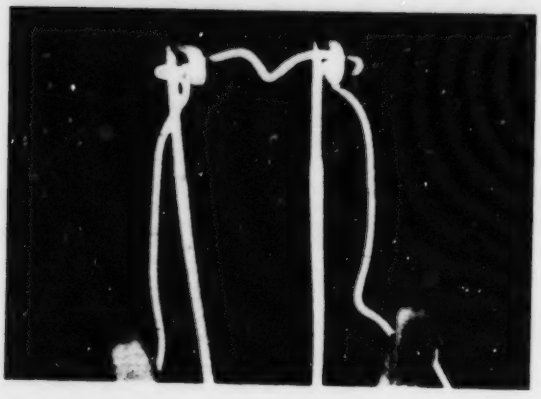
FIGURE 5: (continued)



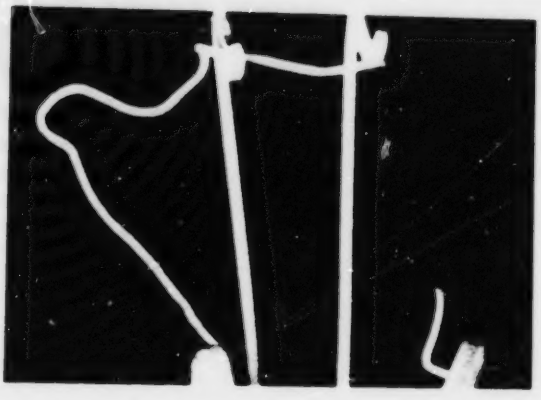
New filament. No appreciable sign of deformation.



48 hours age. No appreciable deformation due to impact.



85 hours age. No appreciable deformation due to impact.



144 hours age. No sign of local stretch, but cold fracture has occurred.

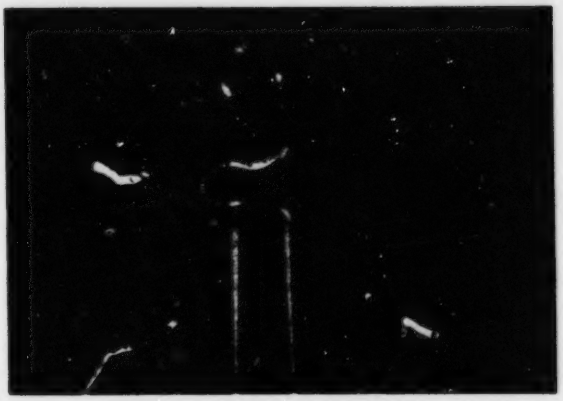
TEST PARAMETERS
3300g
1.0 msec
0 volts d.c.
x21 mag.

FIGURE 5: (continued)

Impact at approximataly 4000 g, 0.35 msec. at 28 volts d.c.

← This new filament (x17), showing both cold general deformation and local stretch could be mistaken for a hot filament subjected to low impact.

→ This new filament (x14), which flailed violently under the influence of resonance, shows severe general deformation and local stretch not apparent in the new hot filaments shown in Figure 5.

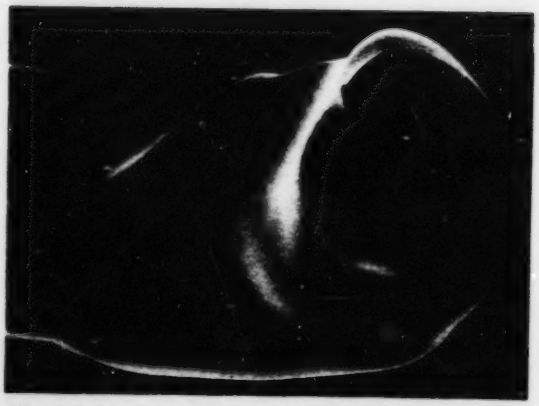


Impact at approximately 4000 g, 0.28 msec. at 0 volts d.c.

FIGURE 6: FILAMENT EXCITED BY RESONANCE

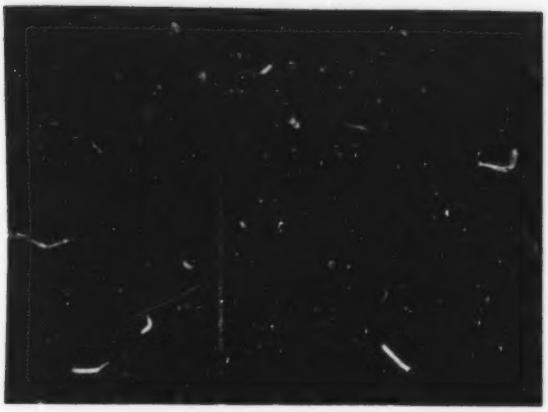
Cold fractured filament (x2500), after impact at 1400 g, 1.5 msec. Note the typical intergranular fracture face.

Severely notched cold fractured filament (x2100). Note the distinct sharp intergranular fracture face.

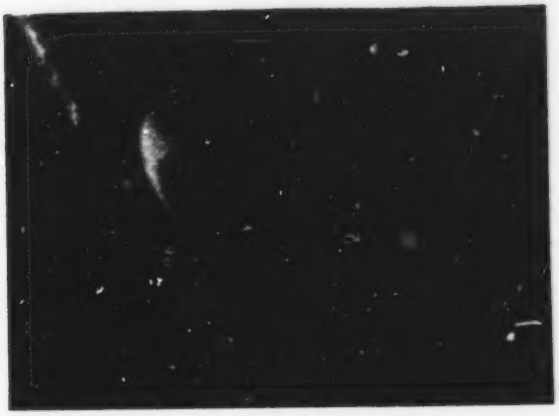


Severely notched cold fractured filament (x2800). Note the extreme reduction in cross-section at the fracture face.

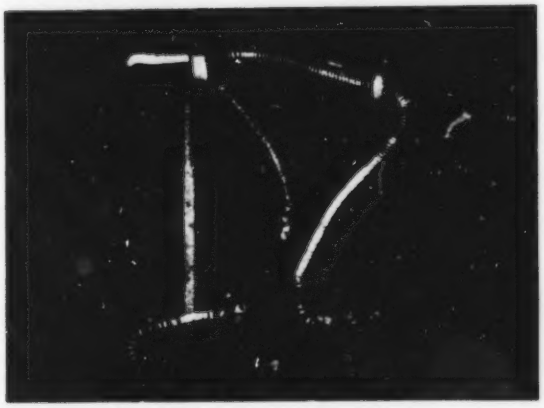
FIGURE 7: COLD FRACTURES



Filament (x14) after hot fracture. Violent flailing has occurred due to resonance.

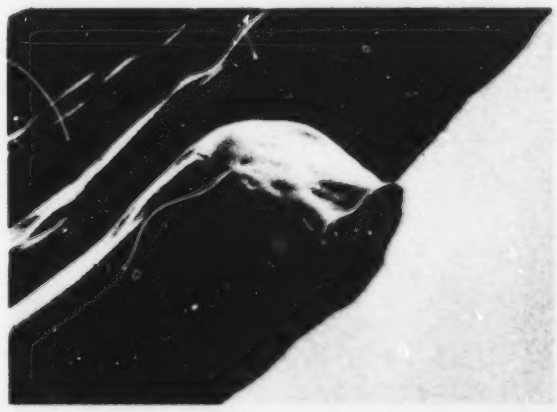


Fracture face (x1400). Noted appearance and "aneurism".



Filament (x21) after hot fracture.

Fracture face (x210). Note rewelding of broken segments.



Examples of hot fracture faces (x2800 left; x2100 right). Note rounded fracture edges.

FIGURE 8: HOT FRACTURES

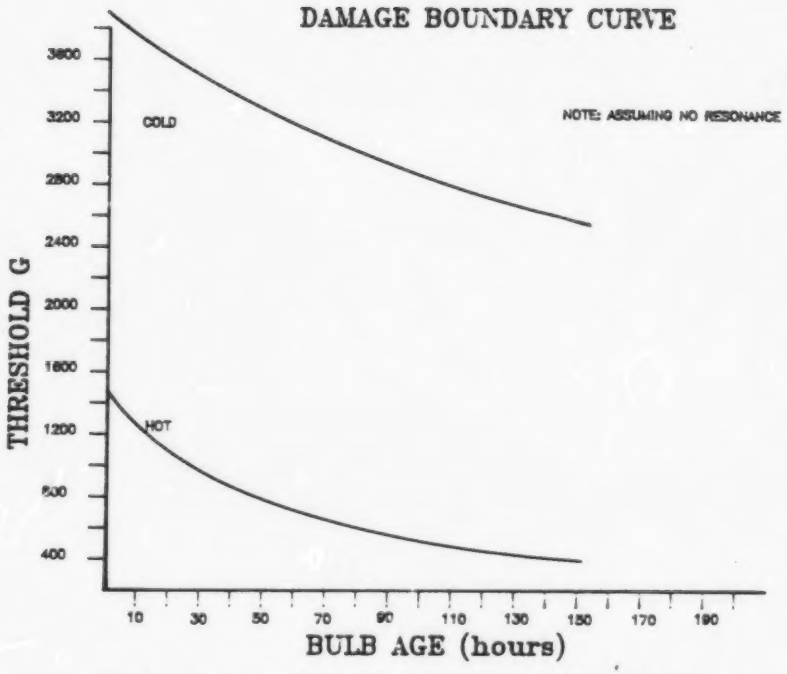


FIGURE 9: AGE VS. IMPACT BOUNDARIES

9. ILLUMINATION TIMES

If, as a result of some initial impact, a warning light receives a signal to change state and has time to do so prior to final impact, then the light will indicate a condition that did not exist prior to initial impact i.e., a "false" signal.

Tests have establised that the GE327 requires approximately 50 msec to reach incandescence (or lose incandescence) from the time voltage is applied (or removed); by comparison, the GE313 requires approximately 50 msec from power "on" and 100 msec from power "off".

When the total aircraft impact sequence is of shorter duration than these times, a "false" signal is impossible, but when the impact is of longer duration, "false" signals could be generated.

Longer duration crashes are generally of lower g levels but local impact forces at the instrument panel capable of causing damage to the bulbs typically occur at the beginning of a single impact crash sequence, therefore the likelihood of a false reading is reduced. False indications are more likely to occur in the case of multiple impact e.g. wire, tree or tower strike, accidents.

10. PROCEDURES

On-Site

On-site activity consists primarily of identifying selected light bulbs and removing them for subsequent examination.

It will prove useful in conducting a comparative analysis to examine as large a number of bulbs as possible, therefore it is preferable to remove too many bulbs rather than too few.

On-site analysis should be kept to a minimum.

The following guidelines are suggested:

1. The complete mounting assembly or panel should be removed as a unit whenever possible. Do not remove single bulbs unless absolutely necessary.
2. If it is absolutely necessary to remove individual bulbs, note the exact location of each bulb, secure it in place with tape in order to maintain its position relative to the group of bulbs, and apply an identification tag or tape to each.
3. Place groups of bulbs or individual bulbs in suitable protective envelopes or containers. Avoid damage due to handling or shipping.
4. Send bulbs, with a completed 'Light Bulb Field Information Sheet' (Figure 10), to appropriate regional laboratory for detailed examination.

Regional Laboratory

The regional laboratory may remove the individual bulbs from their next assemblies and inspect them under an optical microscope to determine the general state of the filament or it may forward the assemblies to the specialized laboratory.

The following guidelines for examination are suggested:

1. Refer to the documents from the on-site investigation.
2. Remove the individual bulbs, making sure that the identification tag or tape is preserved.
3. Examine each bulb individually under a microscope having at least x30 magnification. Note condition of the filament. As a precaution, photograph selected bulbs through the microscope, if desired.

4. Never attempt to remove the glass envelope from a bulb.

5. Record findings on the 'Light Bulb Analysis Laboratory Checklist (Figure 11), forward with carefully packed bulbs, photographs and other relevant information, to the specialized laboratory for confirmation of findings.

Specialized Laboratory

The specialized laboratory typically examines selected bulbs, with the glass removed, under a scanning electron microscope and relates the findings to all other known facts about the accident being investigated. In this way, the light bulb physical condition can be used to infer the bulb operating condition ("on" or "off") immediately prior to impact; from this, the aircraft parameters prior to impact can be deduced.

Each specialized laboratory has its own set of equipment, its own staff members with their individual skills and experience, and its own distinctive history of past investigations. No general procedure which could apply to all such laboratories is offered, but a few practical suggestions based on Canadian experience are noted below:

1. In case the internal parts of the bulb are damaged during the removal of the glass, selected bulbs must be photographed through the glass as a precautionary measure.

2. To remove the glass from the metal base, a form of small glass cutter has been found satisfactory. Hold bulbs with the metal base up so that the glass falls freely away from the filament when cut.

3. Glass removal technique can be developed using sample bulbs until the laboratory specialist feels comfortable in carrying out this operation.

4. During glass removal, small fragments of glass occasionally adhere to the filament and other internal parts due to static electricity. These should not be confused with glass that has fused to internal parts during hot impact.

5. To supplement the information in this Manual, each specialized laboratory should obtain a copy of the ASE report by applying to:

Aviation Safety Engineering Branch
Canadian Aviation Safety Board
P.O. Box 9120
Alta Vista Terminal
Ottawa, Canada
K1G 3T8

11. FINAL ANALYSIS

Although the analysis of bulbs alone can yield much information, this must be checked against other known facts for confirmation of findings or to eliminate ambiguities or misinterpretations.

The checklist and information sheet are invaluable sources of supplementary information and must be consulted during the final analysis.

Where a number of indicator bulbs are known to have been subjected to essentially the same forces during impact e.g., all bulbs in an annunciator panel, it is strongly recommended that they be analyzed as a group so that cross-checks can be accomplished. The comparative analysis is increasingly important in low g-level accidents where damage is minimal. In this way confidence in the individual analyses is enhanced.

Similarly, it is recommended that where two or more bulbs are provided to illuminate a single indicator, these bulbs be analyzed together.

INVESTIGATOR _____ AIRCRAFT _____ DATE _____

AIRCRAFT IMPACT SUMMARY
WARNING SYSTEM LIGHT GENERAL CONDITIONS

FIGURE 10

LIGHT BULB ANALYSIS FIELD INFORMATION SHEET

INVESTIGATOR _____ AIRCRAFT _____ DATE _____

Ref. No.	Function	Bulb Type	Glass Intact?	Filament Fracture?	Deform. gen	Deform. loc	Estimated age	Comments

FIGURE 11

LIGHT BULB ANALYSIS LABORATORY CHECKLIST